

Purdue University

Purdue e-Pubs

Historical Documents of the Purdue
Cooperative Extension Service

Department of Agricultural Communication

7-1-1970

Insulation and Heat Loss

Purdue University Cooperative Extension Service

Follow this and additional works at: <https://docs.lib.purdue.edu/agext>

Agricultural Engineers' Digest

Purdue University Cooperative Extension Service, "Insulation and Heat Loss" (1970). *Historical Documents of the Purdue Cooperative Extension Service*. Paper 66.
<https://docs.lib.purdue.edu/agext/66>

For current publications, please contact the Education Store: <https://mdc.itap.purdue.edu/>

This document is provided for historical reference purposes only and should not be considered to be a practical reference or to contain information reflective of current understanding. For additional information, please contact the Department of Agricultural Communication at Purdue University, College of Agriculture: <http://www.ag.purdue.edu/agcomm>

This document has been made available through Purdue e-Pubs, a service of the Purdue University Libraries. Please contact epubs@purdue.edu for additional information.

Admin - yes

Miss

AED

Insulation and Heat Loss

AED-13

AGRICULTURAL ENGINEERS' DIGEST

KEEPING LIVESTOCK BUILDINGS WARM— How to Figure Insulation, Heat Loss and Supplementary Heat

Introduction

The growing numbers of both livestock and poultry being raised in enclosed confinement point to one thing—the desire, on the part of feeders, to reach and maintain optimum animal or bird performance.

Effective livestock buildings have a variety of features designed to provide an optimum environment of temperature, moisture, air movement and gas content; features like tight construction, insulation, vapor barriers, insulated doors and windows, and ventilation systems.

Tight Construction

The enclosed building should be reasonably tight. Loose construction and unplanned openings make it difficult to control the amount and movement of ventilation air.

Insulation

Insulation is any material that reduces the rate at which heat is transferred from one area to another. Although all building materials have some insulation value, the term “insulation” is generally reserved for a family of products designed to provide this one service.

Insulation has several functions. *First*, it helps conserve heat during periods of cold weather (Fig. 1). The conservation of animal or bird heat is necessary to maintain desirable housing conditions without the addition of unrealistic amounts of supplemental heat.

Second, insulation helps reduce the rate of heat gain in hot weather (Fig. 2). The temperature of the walls and roofs of buildings exposed to direct sunlight is as much as 50°F above air temperature.

One result of reducing heat loss and heat gain is a desirable reduction in the daily changes in indoor temperatures. Fig. 3 illustrates that an in-

sulated building is cooler in the warm part of the afternoon and warmer in the cold early morning hours. The total temperature variation during the day is reduced.

Third, surface condensation—“sweating”—can be controlled. In a poorly insulated building, the inside ceiling and wall surfaces become cold in the winter, bringing discomfort to animals nearby. When the surface temperature is low enough, the air next to the surface becomes saturated and moisture condenses (Fig. 4). If the surface temperature is below freezing, frost forms. Well-insulated buildings reduce the possibility of condensation and frost by keeping the walls and ceiling relatively warm.

Fourth, correct foundation insulation reduces frost heaving, keeps floors warmer, and reduces heat losses. Insulate the *outside* of the foundation wall if possible (Fig. 5): the wall above the floor will be warmer, reducing condensation; the foundation below grade will be warmer, reducing the hazard of frost heaving; the outer edge of the floor will be warmer, increasing animal comfort; and total heat losses from the building will be reduced. Traditional methods of placing insulation inside the foundation wall and under the floor will reduce heat loss only through the floor.

Types of Insulation

The most common insulation consists of bulky, porous, lightweight materials with countless air spaces. The lighter the material is, the better are its insulating qualities. Generally, the more air pockets in the material, the better it insulates. Some building materials, like wood, are good insulators, while others, like concrete and metal, are poor insulators.

Manufactured insulation can be bought in several common forms. Answering the following questions

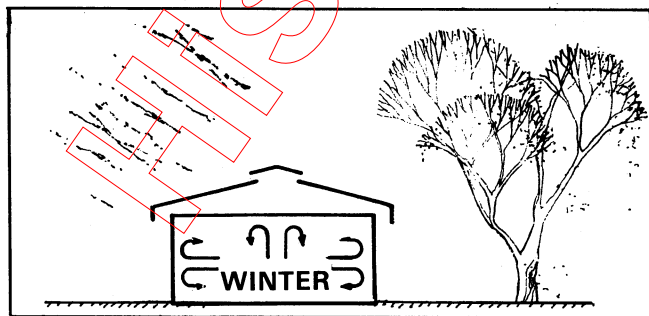


Figure 1. Insulation reduces the rate of heat loss from buildings during cold weather.

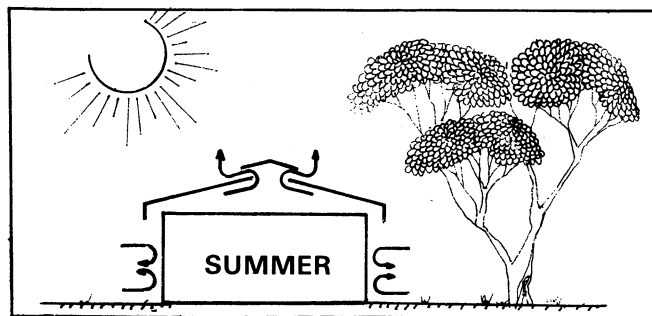


Figure 2. Insulation reduces the rate at which heat passes into a building during hot weather.

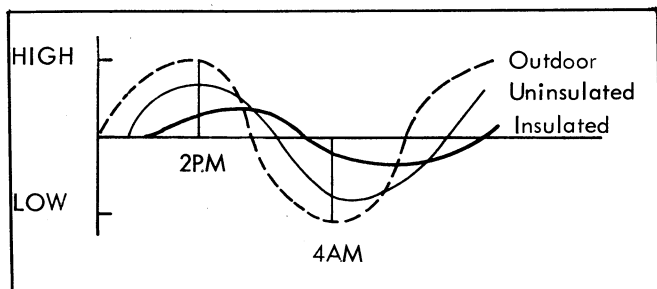


Figure 3. Insulation reduces temperature extremes in a building.

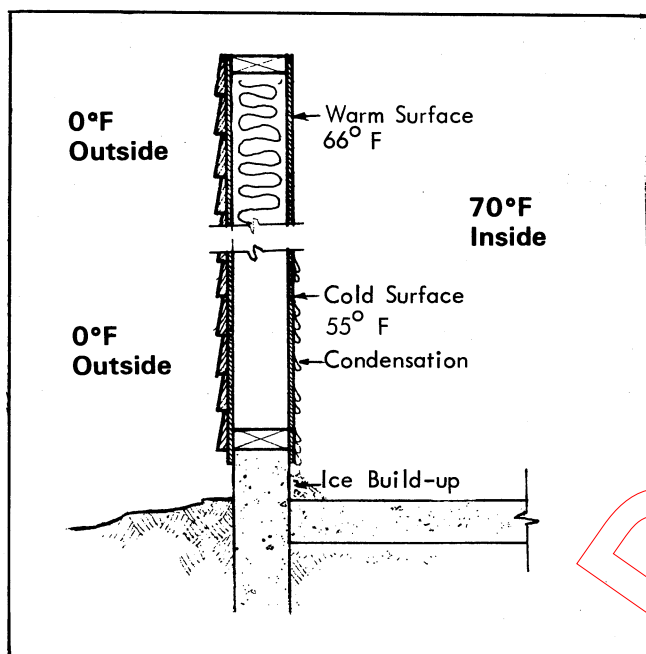


Figure 4. When warm, moist air comes into contact with a cold surface, condensation occurs. Insulation helps to control sweating by making the wall and ceiling surfaces warmer.

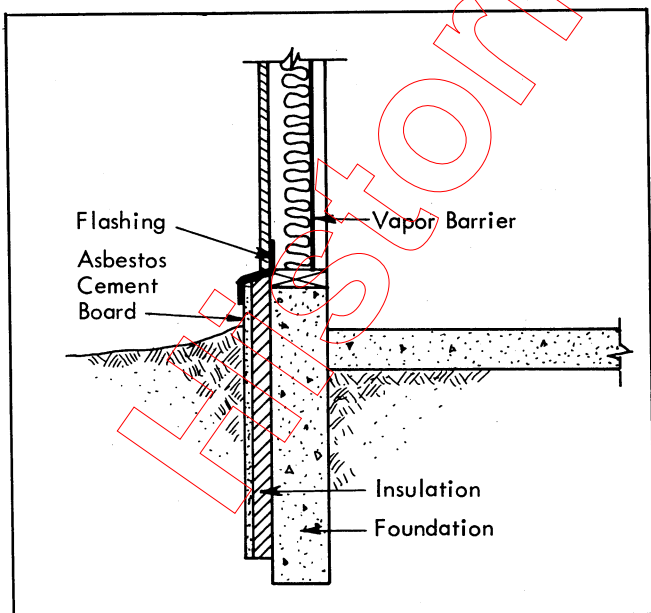


Figure 5. Method of placing perimeter insulation

will help determine the form to be selected for a particular job:

- How is it to be used? Is it to be purely for insulation, or does it also need to have some structural qualities?
- How adaptable is it to the particular use?
- What is its relative cost?
- Can it be installed easily?

Loose-fill insulation is packaged in bags. Almost all the common insulations—mineral wool, vermiculite, granulated cork, and others—come in this form. Loose-fill insulation is especially adapted for use in ceilings of existing buildings. Special precautions must be taken, however, when it is used in side walls. Settling does occur and some parts of the wall may not be adequately insulated. A vapor barrier must be provided on the warm, or room, side of the wall and ceiling.

Insulation batts and blankets are among the easiest and cheapest ways to add insulation to a farm building. They come in thicknesses of 1"-6" and in widths to fit either 16" or 24" stud spacings. Many of these have a vapor barrier attached to one side (see Vapor Barriers, p. 3).

Insulation board has some rigidity as well as insulation value. For use in livestock buildings, it must be treated to resist moisture. Some insulation boards have a vapor barrier on one side. Insulation board must be protected from physical damage by animals and equipment. Follow the manufacturer's recommendations for installing insulation board on spaced supports in a ceiling, roof, or wall.

Block or rigid insulation is usually used for perimeter or floor insulation. Fig. 5 shows how perimeter insulation should be placed to insulate the edges of a concrete floor. Materials used for perimeter insulation *should withstand moisture*. The materials most commonly used for this purpose are expanded polystyrene, foam glass, polyurethane or asphalt-impregnated rigid insulations.

Air space, as insulation, should not be less than 3/4" wide, because its effectiveness decreases rapidly as its width decreases. On the other hand, it should not be over about 4" wide, or convection currents will reduce its insulating value.

Reflective insulation is made from metallic foil such as aluminum foil, placed so that there are air spaces around it. It reflects almost all of the radiant heat that strikes it. Since only part of the heat to be retarded is radiant heat, reflective insulations need to have several air spaces to resist the flow of heat by conduction and convection.

Reflective insulation is highly efficient in resisting the flow of heat downward. For this reason it is effective in keeping out summer heat and allows the interior of the building to cool rapidly at night. *Foil insulation* is not commonly used as winter insulation in farm buildings.

Additives to concrete have been suggested as a means of increasing the insulation quality while retaining the strength of ordinary concrete. Some materials (for example, expanded shale, ground corncobs, or wood shavings) when substituted for some of the concrete aggregates will increase the insulation value of that concrete, BUT at a considerable reduction in the strength of the concrete. At present, no additive has been proved without bias to insulate concrete without a reduction in strength.

Selecting Insulation

All building materials have some insulation value, but the amount varies considerably. Fig. 6 shows how thick building materials would need to be to have the same insulation value as a 1" glass wool batt. For example, it takes 2.96" of plywood or 46.3" of concrete to equal the insulation value of 1" of glass wool.

Insulation, as well as other building materials, can be rated according to its ability to resist the flow of heat. This is commonly referred to as the "R" value. The relative insulation values of some of the common building materials are shown in Table I (Appendix). The R, or insulation value, may be given per inch of thickness, or for the total thickness of a material.

Other means of expressing the value of insulation are the "K", "C", or "U" values. The K value gives the amount of heat (in British thermal units) per hour that will pass through a piece of material 1" thick and 1' square, when the temperature difference between the two sides is 1°F. The C value is like K, except it's given for a total thickness: K glass wool = .27; C 3" glass wool = 0.09. The U value (over-all coefficient of heat transmission) is the amount of heat in Btu's that will pass through a complete wall, ceiling, or floor construction, 1' square, in one hour per degree of temperature difference between the air on the warm side and the air on the cold side. The U value is $1/R$.

In the following discussion, the R value is used because the insulation value of a wall is easier to calculate with this value than with the others. Recently, the insulation industry adopted the R value and many insulations are marked with their R values.

Tables II, III, and IV (Appendix) show a number of the more common wall sections used in farm buildings today and the relative insulation value of each. These show that a small amount of insulation can make a big difference in heat-flow resistance. Table V shows insulation values for other types of construction, including roofs and ceilings.

The amount of insulation needed in farm buildings will vary according to winter temperatures. (See Fig. 7.)

Protect Insulation From Moisture- Use Vapor Barriers

In livestock buildings and other buildings where the relative humidity is high, it is extremely important to protect the insulation from moisture. Moisture, in the form of water vapor, tends to move from the warmer moist areas to the cooler outside. The moisture enters the wall, moves outward, and condenses when it reaches a cold enough area. Condensed water in the wall greatly reduces the value of the insulation and may damage the wall.

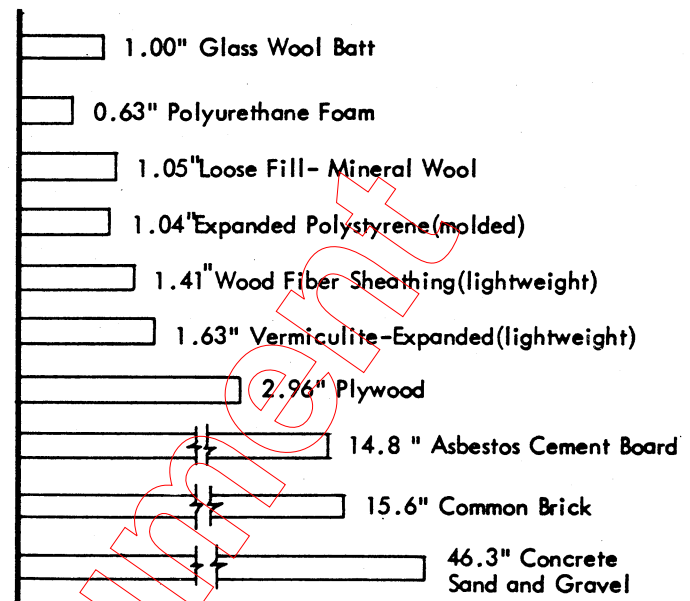
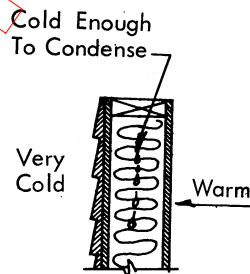


Figure 6. Material thickness required for equal insulation value.

Climate Zone	Total Resistance (R)	
	Walls	Ceilings
Mild	9	12
Moderate	9-14	16
Cold	14	23

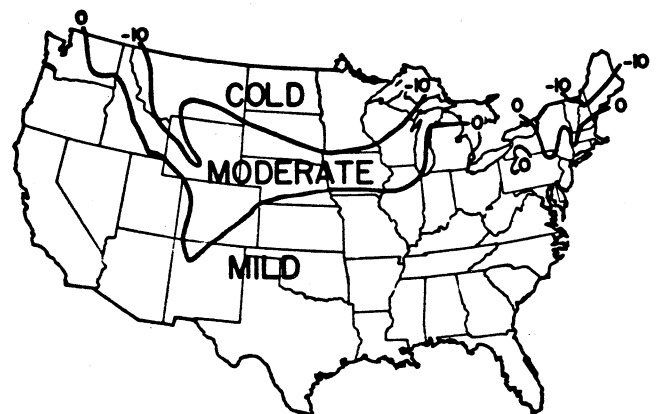


Figure 7. Recommended insulation

Amount of insulation to use depends on a number of factors. The map shows winter temperature zones. The table shows recommended "R" values for farm buildings.

To eliminate this flow of moisture, a supplemental vapor barrier should be placed near the warm side of the wall. (Fig. 8.) Immediately beneath the interior lining material is best.

Common vapor barriers are aluminum foil, 4 mil plastic film, and some of the asphalt-impregnated building papers. Table VI (Appendix) shows the water vapor transmission ratings of some of our common vapor barriers and building materials. The numbers represent the amount of vapor transmission, so the smaller numbers represent the better vapor barriers. A material with a rating below 1.0 is usually considered a good vapor barrier.

Consider the construction joints of the materials when comparing the water vapor transmission values. Vapor barrier materials are lapped to prevent moisture from entering through the joints. In concrete sandwich walls, if the concrete is mixed according to instructions, no vapor barrier is required.

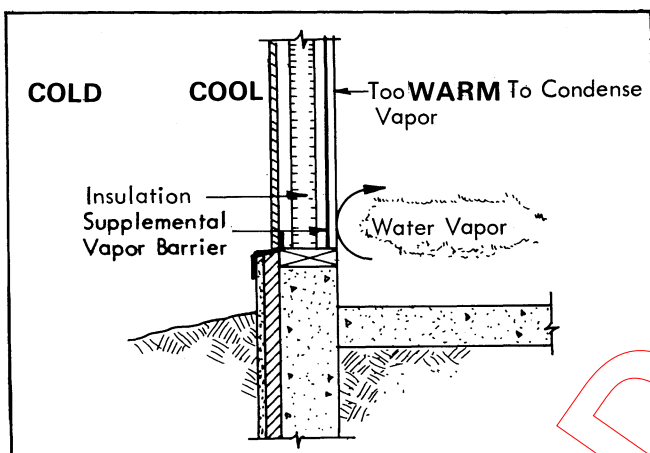


Figure 8. Vapor barriers prevent the movement of water vapor into wall and ceiling spaces and materials.

Applying Different Types of Insulation

Each type of insulation has its application problems. Follow the manufacturer's recommendations.

Batts or blankets must be protected from moisture. Moisture will destroy a batt's insulation value. The vapor barrier on many batts is not sufficient for livestock buildings. Use a separate vapor barrier between the batts and the inside wall or ceiling lining.

Because mechanical damage permits moisture to enter batt insulation, an inside wall and ceiling lining is almost always required. A batt with a vinyl backing can be applied to ceilings without a ceiling lining, but they usually sag in time. These batts are stapled directly to the ceiling joists or rafters.

If *insulation board* is used alone, it is difficult to get the builder to use the 3" required in the roofs of livestock buildings.

Most insulation boards used in farm buildings have been chemically treated to make them moisture resistant. Some boards have a plastic covering that gives them a good vapor barrier.

Many builders span too large a distance when applying insulation board. Follow the manufacturer's recommendations. When insulation board is used as a false ceiling, supports can be located up to 24" on center, depending on the thickness of the board.

Some rigid plastic foams are resistant to the absorption of moisture, but others—the low-density beadboards—offer little resistance. The vapor transmission ratings of the different types of foam range from 0.4 to 5.8 perms. Use a separate vapor barrier if the perm rating is above 1.0.

Some foam is applied by butting the square edges of the rigid boards together. A small amount of shrinkage leaves small cracks (sometimes up to an eighth of an inch). Moisture can escape, condense on the cold roof and drip onto the foam. Tongue-and-groove edges help eliminate the problem. Taping the joints has not been satisfactory. Taping the joints on newer foams with a plastic film on one side has shown greater promise.

Use enough insulation. Learn the insulation value of the material and use enough to provide a satisfactory insulation value. Consider summer as well as winter conditions.

Don't be concerned about the insulation value of the lining. Apply the insulation required inside the wall. Choose a lining material for its durability, ease of cleaning, and appearance.

Provide a good vapor barrier. Insulation materials that possess a satisfactory perm rating will still require vapor-tight joints.

Protect insulation from rodents and birds. Also protect against damage by animals, workers, and equipment. Few insulations applied with one side exposed have proved to be satisfactory in livestock buildings.

Insulate all areas. In metal-frame or masonry buildings columns or other assemblies may extend through the wall, and if uninsulated may be cold, wet, and frosted. Since wood has some insulating value, the studs and rafters in wood-framed buildings have not caused problems when used for livestock housing.

Characteristics of Heat and Moisture

A thorough understanding of heat transfer is beyond the scope of this presentation, but a basic understanding of heat and moisture behavior is necessary. *Heat* is defined as a form of energy which is transmitted from one body to another because of temperature difference. "Temperature" is a relative term for the magnitude of heat, the relative warmth of a material, and not the quantity of heat. The British thermal unit (Btu) is the quantity of heat required to raise one pound of water one degree Fahrenheit.

This heat is subdivided into latent heat and sensible heat. *Latent heat* is that heat involved in a change of state without a change of temperature. For example, latent heat is required to change water at 212°F into vapor at 212°F. Latent heat is usually given the symbol Q_L .

Sensible heat is heat associated with a change of temperature, either increasing or decreasing. That is, sensible heat is required to change a room's temperature. This is usable heat, which is symbolized Q_s .

The *total heat*, Q_A , is simply the summation of the latent and sensible heats. The equation is $Q_A = Q_L + Q_s$. The quantity of each of these three heats is measured in Btu's.

Heat is transferred from one location to another by conduction, convection, radiation, or any combination thereof. Conducted heat passes from one place to another by warming the material that

separates a warm area from a cold area. Convected heat is transmitted by a moving fluid, such as circulating air. Radiation involves the passage of heat through a space without warming the space, such as the sun heating the earth.

In farm buildings, heat is lost or gained by conduction through building materials, by air currents moving over the inside or outside surfaces, and by radiation from warm surfaces.

Temperature-Moisture Relationships

The air exhaled by all animals contains moisture in the form of vapor. For example, an average-size lactating dairy cow will exhale over one pound of water per hour. Body heat vaporizes water in the lungs.

The body metabolism of the animal also causes a release of sensible heat to surrounding air—about 2,500 Btu/hr for a cow.

The released amount of latent and sensible heat is variable. Total heat production per pound of body weight increases with body weight and animal activity; it decreases with maturity and higher air temperatures. The data given in Table VII (Appendix) are approximate and are for the conditions stated.

The latent heats in Table VII are used to determine the amount of moisture in the air that must be disposed of. The sensible heats in Table VII are used not only for warming the incoming ventilation air, but also for maintaining the building temperature.

The principle of moisture-holding capacities of air at various temperatures and humidities is basic to ventilation. A 20°F rise in air temperature doubles the moisture-holding capacity of the air. For example, 40°F air at 50% relative humidity contains 18 grains of water per pound of air. If this air is heated to 60°F at 50% relative humidity, it can hold 36 grains per pound of air. Its moisture-holding capacity has doubled. This phenomenon is the reason that ventilation air removes moisture from buildings.

Cooling air 20°F halves its water-holding capacity. The excess may appear as condensation on cooler surfaces within the building.

SENSIBLE HEAT GAIN = SENSIBLE HEAT LOSS

The sensible heat produced inside a building must equal the sensible heat loss, if the building temperature is to remain constant. The separate factors are:

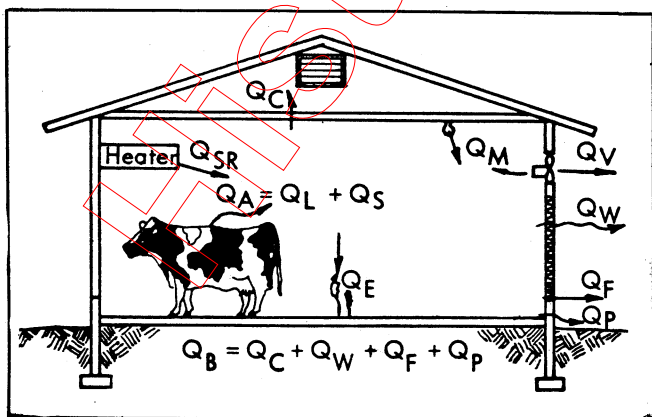


Figure 9. Winter Conditions—heat into and out of building spaces.

Heat gain will be from total animal heat, heat from motors, lights, etc., and supplementary heat, and can be expressed $HEAT\ GAIN\ Q_R = Q_A + Q_M + Q_{SR}$.

Heat loss will be from building loss, ventilation loss, and latent heat to evaporate water, and can be expressed $HEAT\ LOSS\ Q_T = Q_B + Q_V + Q_E$.

Since all the heat produced will eventually be lost from the building if the inside temperature remains constant, then $Heat\ Loss = Heat\ Gain$ or $Q_T = Q_R$.

Animal sensible heat + heat from motors, lights, etc., + supplementary heat = building loss + ventilation loss + latent heat to evaporate water.

$$Q_S + Q_M + Q_{SR} = Q_B + Q_V + Q_E$$

Heat Gain Design Procedure

At this point we are ready to determine the quantity of heat which is available for ventilation and heating the building. This may best be illustrated by an example.

Assume that we wish to house 150 hogs in a growing-finishing operation. The hogs will go into the house at 50 lbs and remain until they reach 200 lbs. How much heat will the hogs produce at each weight? At 50 lbs we have:

$$\begin{aligned} \text{Sensible heat produced} &= (Q_s \text{ from Table VII}) \times \\ &\quad (\text{number of hogs}) \times (\text{number of cwt. per hog}) \\ &= (293) \times (150) \times (0.5) \\ &= 22,000 \text{ Btu/hr} \end{aligned}$$

Using the same procedure for the 200-pound hogs we get:

$$\text{Sensible heat produced} = (293) \times (150) \times (2.0) = 88,000 \text{ Btu/hr}$$

Smaller pigs produce less heat and therefore need more supplemental heat than larger ones. Use 22,000 Btu/hr to design the heater needed.

The sensible heat from motors, lights, etc., is small when compared to the total and may be ignored. The supplementary heat is what we want to find—it is the "furnace" heat needed to maintain desired conditions.

Temperature Balance Design Procedure

The loss of heat from the building involves losses through the ceiling or roof, through the walls, and through the perimeter or foundation. All the losses are directly related to their respective insulating values.

There are also ventilation losses because cold air is heated and exhausted to remove excess moisture from the building. The moisture comes from the respiration of the animals, urine and feces, and spilled drinking or cleaning water.

Building losses may be found by applying $Q_B = (t_i - t_o) \times A/R$, where Q_B is the building heat loss in Btu/hr, A is the area of the wall or ceiling in square feet, R is the resistance to heat transfer, t_i = the inside temperature of the building, and t_o = the temperature of the outside air.

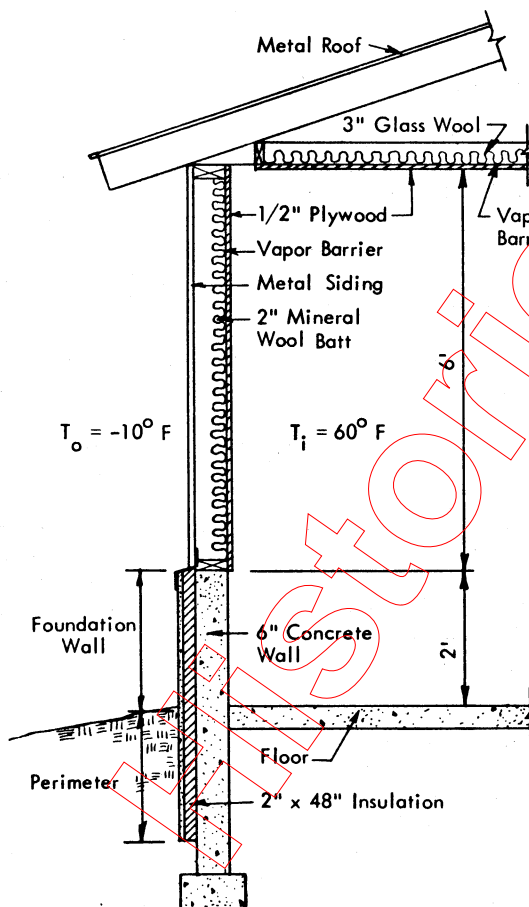
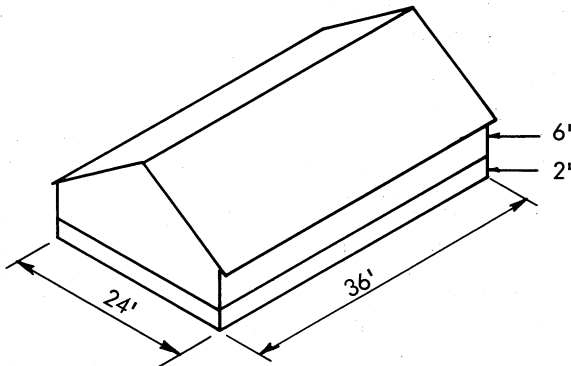
Temperatures—The desired inside temperatures, t_i , are given in Table VII, p. 12. Heat loss will be greatest when outside temperatures, t_o , are low. Experience and research have shown that the reasonable design outside winter temperatures are as shown in Fig. 10, p. 9.

It is assumed, for temperature and moisture balance, that there is sufficient air circulation within the shelter to provide fairly uniform conditions.

SAMPLE PROBLEM

The design procedure for temperature balance may be best illustrated by using a sample problem. Assume a swine farrowing building as sketched below. Outside temperature will be -10°F . Let's work through the six steps on the accompanying "Work Sheet-Heat Loss," (p. 7) so our final result is the amount of supplemental heat required.

24' x 36' 16-Sow Farrowing House



Step I

List the length, width, wall height, and foundation height and calculate and record the linear feet of wall, wall area, foundation area, and ceiling area. The resistance of the frame wall is calculated as follows from Table I:

Number 7. inside surface	0.68
4. 1/2" plywood	0.63
1. 2" wool (2 x 3.7)	7.40
6. air space	0.90
metal is zero	0
7. outside surface	0.17
	<hr/> 9.78

The R for the 6-inch concrete foundation wall with 2-inch exterior insulation is 8.50 as found in Table IV (Appendix). Note: If concrete is uninsulated, $R = .48$, and heat loss is 35,000 Btu/hr instead of 1976 Btu/hr.

The R value for the ceiling is 13.94 from item 4, Table V (Appendix).

Step II

The Q values of the ceiling, walls, foundation, and perimeter are found by placing the appropriate values from Step I into the equations and multiplying.

The 2.22 in the perimeter equation assumes a 2-inch by 24" polystyrene perimeter insulation. Table V, No. 12.

The heat loss due to the building is a sum of the ceiling, wall, foundation and perimeter losses.

Step III

The ventilation losses Q_v are based upon the volume of air moved and the temperature differential. The volume of air is the building volume ($L \times W \times H$) times the recommended minimum ventilation as found in Table VII (assume a well-constructed tight building so that there is no leakage around doors and windows). Entering these values in the Q_v equation will give the ventilation heat loss. The 0.018 constant in the equation accounts for the specific heat of air (0.24) and the specific volume of air (0.075 lbs/cu ft).

Step IV

The total heat loss, Q_T , is the sum of Q_b from Step II and Q_v from Step III.

Step V

The total heat produced, Q_R , is as discussed previously and as outlined on the Work Sheet. Assume 330-pound sows.

Step VI

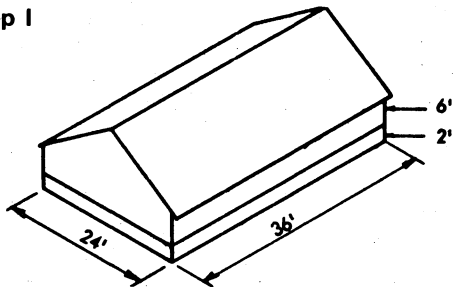
The supplemental heat required, Q_{SR} , is the difference between the total heat loss, Q_T , in Step IV and the total heat produced, Q_R , in Step V.

From the example we found that we needed 26,015 Btu/hr of supplementary heat. The heating unit to install in this building should have a minimum heat output of about 27,000 Btu/hr.

If electric heat is desired, divide the supplementary heat by 3,413, giving the kilowatt hours needed. For our example above, $26,015 \div 3,413 = 7.6$; therefore the electric heater should have a minimum size of 8 Kw-hr.

WORK SHEET—HEAT LOSS

Step I



Building Dimensions -- feet

Length =	<u>36</u>
Width =	<u>24</u>
Wall height =	<u>6</u>
Foundation height =	<u>2</u>
Linear feet of wall (also foundation) =	<u>120</u>
Ceiling area =	<u>864</u>
Wall area =	<u>720</u>
Foundation area =	<u>240</u>

R Values

Ceiling =	<u>13.94</u>
Wall =	<u>9.78</u>
Foundation =	<u>8.50</u>
Perimeter =	<u>2.22</u>
$t_o =$	<u>-10 °F</u>
$t_i =$	<u>60 °F</u>
temp diff (Δt) =	<u>70 °F</u>

Step II

Heat loss due to building (Q_B)

$$Q_{\text{Ceiling}} = \frac{(\Delta t) \text{ times (Ceiling area)}}{(R \text{ ceiling})}$$

$$Q_C = \frac{(70) \times (864)}{(13.94)} = \underline{4,339} \text{ Btu/hr}$$

$$Q_{\text{Walls}} = \frac{(\Delta t) \text{ times (Wall area)}}{(R \text{ wall})}$$

$$Q_W = \frac{(70) \times (720)}{(9.78)} = \underline{5,153} \text{ Btu/hr}$$

$$Q_{\text{Foundation}} = \frac{(\Delta t) \text{ times (Foundation area)}}{(R \text{ foundation})}$$

$$Q_F = \frac{(70) \times (240)}{(8.50)} = \underline{1,976} \text{ Btu/hr}$$

$$Q_{\text{Perimeter}} = \frac{(\Delta t) \text{ times (Linear feet of wall)}}{(R \text{ perimeter})}$$

$$Q_P = \frac{(70) \times (120)}{(2.22)} = \underline{3,780} \text{ Btu/hr}$$

$$Q_B = Q_C + Q_W + Q_F + Q_P = \underline{\underline{15,248}} \text{ Btu/hr}$$

Step III

Heat loss due to ventilation (Q_V)

$$Q_V = (\text{cu ft air/hr}) \text{ times } (\Delta t) \text{ times } (0.018)$$

$$(\text{cu ft air/hr}) = (L \times W \times H) \text{ times (air changes/hr)}$$

$$(\text{cu ft air/hr}) = (36 \times 24 \times 8) \times (3) = \underline{20,736} \text{ ft}^3/\text{hr}$$

$$Q_V = (20,736) \times (70) \times (0.018) = \underline{\underline{26,127}} \text{ Btu/hr}$$

Step IV

Total heat loss

$$(Q_T) = Q_B + Q_V = \underline{\underline{41,375}} \text{ Btu/hr}$$

Step V

Total heat produced, $Q_S = (Q_S \text{ from Table VII}) \text{ times (number of animals) times}$

$$(\text{number of cwt per animal}) = (320) \times (16) \times (3.0) = \underline{15,360} \text{ Btu/hr}$$

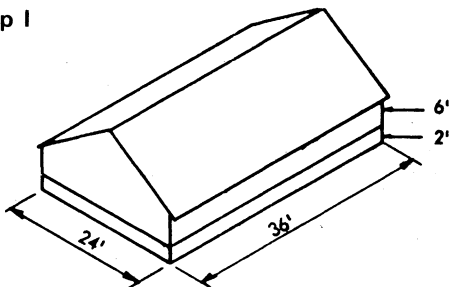
Step VI

Amount of supplemental heat required (Q_{SR})

$$Q_{SR} = Q_T - Q_S \quad Q_{SR} = (41,375) - (15,360) = \underline{\underline{26,015}} \text{ Btu/hr}$$

WORK SHEET -- HEAT LOSS

Step I



Building Dimensions -- feet

Length = _____
 Width = _____
 Wall height = _____
 Foundation height = _____
 Linear feet of wall
 (also foundation) = _____
 Ceiling area = _____
 Wall area = _____
 Foundation area = _____

R Values

Ceiling = _____
 Wall = _____
 Foundation = _____
 Perimeter = _____
 t_o = _____ °F
 t_i = _____ °F
 temp diff
 (Δt) = _____ °F

Step II

Heat loss due to building (Q_B)

$$Q_{\text{Ceiling}} = \frac{(\Delta t) \text{ times (Ceiling area)}}{(R \text{ ceiling})}$$

$$Q_C = \frac{(\quad) \times (\quad)}{(\quad)} = \quad \text{Btu/hr}$$

$$Q_{\text{Walls}} = \frac{(\Delta t) \text{ times (Wall area)}}{(R \text{ wall})}$$

$$Q_W = \frac{(\quad) \times (\quad)}{(\quad)} = \quad \text{Btu/hr}$$

$$Q_{\text{Foundation}} = \frac{(\Delta t) \text{ times (Foundation area)}}{(R \text{ foundation})}$$

$$Q_F = \frac{(\quad) \times (\quad)}{(\quad)} = \quad \text{Btu/hr}$$

$$Q_{\text{Perimeter}} = \frac{(\Delta t) \text{ times (Linear feet of wall)}}{(R \text{ perimeter})}$$

$$Q_P = \frac{(\quad) \times (\quad)}{(\quad)} = \quad \text{Btu/hr}$$

$$Q_B = Q_C + Q_W + Q_F + Q_P = \quad \text{Btu/hr}$$

Step III

Heat loss due to ventilation (Q_V)

$$Q_V = (\text{cu ft air/hr}) \text{ times } (\Delta t) \text{ times } (0.018)$$

$$(\text{cu ft air/hr}) = (L \times W \times H) \text{ times (air changes/hr)}$$

$$(\text{cu ft air/hr}) = (\quad \times \quad \times \quad) \times (\quad) = \quad \text{ft}^3/\text{hr}$$

$$Q_V = (\quad) \times (\quad) \times (\quad) = \quad \text{Btu/hr}$$

Step IV

Total heat loss

$$(Q_T) = Q_B + Q_V = \quad \text{Btu/hr}$$

Step V

Total heat produced, $Q_S = (Q_S \text{ from Table VII}) \text{ times (number of animals) times (number of cwt per animal)} = (\quad) \times (\quad) \times (\quad) = \quad \text{Btu/hr}$

Step VI

Amount of supplemental heat required (Q_{SR})

$$Q_{SR} = Q_T - Q_S \quad Q_{SR} = (\quad) - (\quad) = \quad \text{Btu/hr}$$

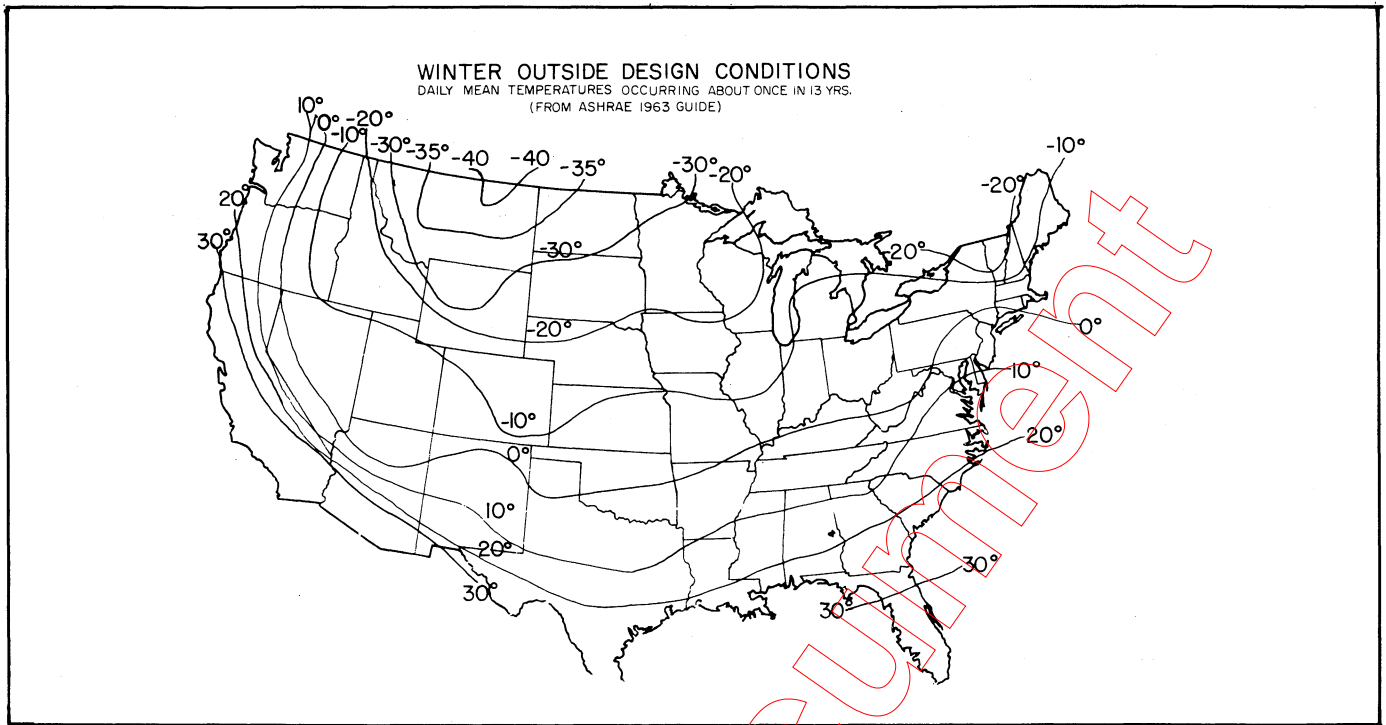


Figure 10. Winter Design Temperature.

APPENDIX

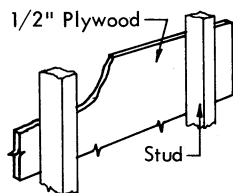
Table 1. Insulation Values for Some Commonly Used Materials.¹

Material	Insulation value ²	
	Per inch thickness	For thickness listed
1. Batt or blanket insulation		
Glass wool, mineral wool or fiber glass	3.70	
wood fiber	4.00	
2. Fill-type insulation		
Glass or mineral wool	3.51	
Vermiculite (expanded)	2.13 to 2.27	
Shavings or sawdust	2.22	
Paper or pulp products	3.57	
3. Rigid insulation		
Wood fiber sheathing	2.27 to 2.63	
Expanded polystyrene, extruded	3.85	
Expanded polystyrene, molded	3.57	
Urethane foam (aged)	5.88	
Glass fiber	4.01	
4. Ordinary building materials		
Concrete, poured	0.08	
Plywood, 3/8"	1.25	.47
1/2"	1.25	.63
Hardboard, 1/4"72	.18
Cement asbestos board, 1/8"03
Lumber (fir, pine) 25/32"	1.02	.98
Wood beveled siding 1/2" x 8"81
Asphalt shingles44
Wood shingles94
5. Window glass, includes surface conditions		
Single-glazed89
Single-glazed with storm windows		1.79
Double-pane insulating glass		1.5 to 1.75
6. Air space (3/4" or larger)90
7. Surface conditions		
Inside surface68
Outside surface (15 mph wind)17
8. Reflective-type insulation		
Aluminum foil	Ceiling	Wall
2 air spaces	5.00	5.92
3 air spaces	7.14	9.11

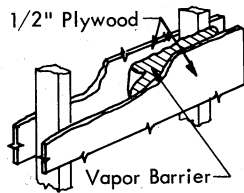
¹ From ASHRAE Handbook of Fundamentals, 1967.

² Mean temperature of 75°F.

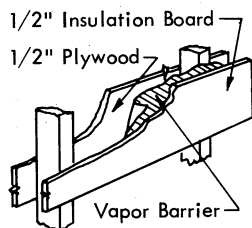
Table II. Insulation Values for Frame Construction With Plywood Siding.



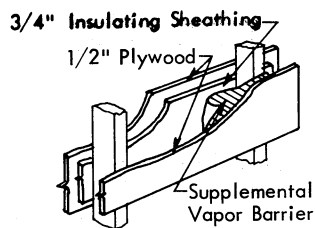
R = 1.48



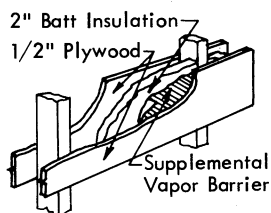
R = 3.01



R = 3.69

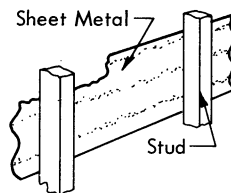


R = 5.00

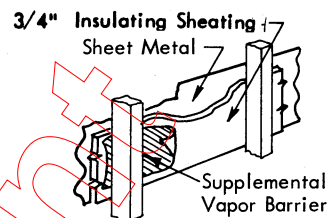


R = 10.41

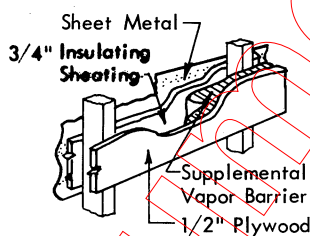
Table III. Insulation Values for Frame and Metal Construction With Metal Siding.



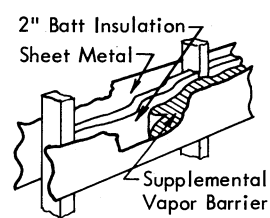
R = 0.85



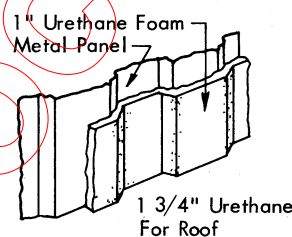
R = 2.83



R = 4.51

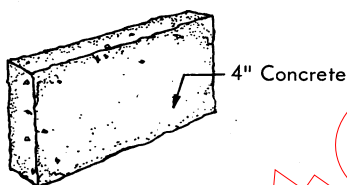


R = 9.22

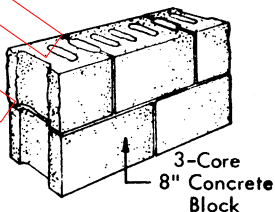


R = 6.73

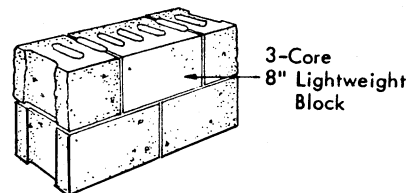
Table IV. Insulation Values for Concrete Wall Construction.



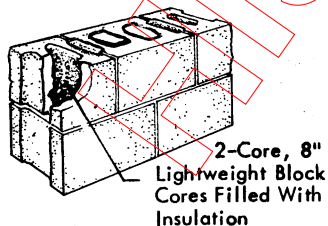
R = 1.17



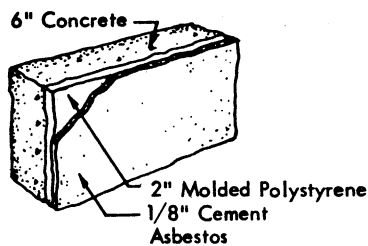
R = 1.96



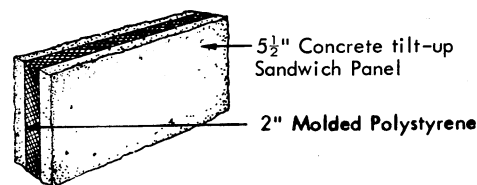
R = 2.85



R = 5.88



R = 8.50



R = 8.27

Table V. Insulation Values for Other Construction.

Roofs and Ceilings	"R"
1. Asphalt shingles, wood sheathing, vented attic space, 1/2" insulating board ceiling	4.95
2. Same as above, but wood shingles	5.45
3. Same as above, but metal roofing on nailing girts.	3.53
4. Metal roofing on nailing girts, vented attic, 3" blanket insulation (mineral wool) 1/2" plywood ceiling	13.94
5. Same as 4, except 4" fill insulation (glass or mineral wool)	16.88
6. Same as 4, except 6" blanket insulation	25.04
7. Metal roof on nailing girts, hay mow, 12" of hay or straw	20 Approx.
Doors	
8. Wood siding, beveled, 3/4" x 10".	1.90
9. Plywood, 3/4" blanket insul, between 2 sheets 1/2" plywood	4.88
10. Plywood, 1 1/2" blanket insul. between 2 sheets 1/2" plywood.	7.65
Floor Perimeter (per foot of length of exterior wall.)	
11. Concrete, without perimeter insulation	1.23
12. Concrete, with 2" x 24" perimeter insulation	2.22

Table VI. Water Vapor Transmission of Common Building Materials, Perms¹

$$1 \text{ Perm} = 1 \text{ Grain/hr-ft}^2\text{-in.hg}$$

Vapor Barriers	
Aluminum foil (1 mil)	0.0
4 mil polyethylene (plastic film)	.08
Kraft and asphalt building paper	.3
Two coats of aluminum paint (in varnish) on wood	.3-5
Common Building Materials	
1" extruded expanded polystyrene	1.2
15 lb tar felt building paper	4.0
1/2" insulation board, uncoated	.50 to .90
1/4" 3-ply exterior plywood	.7
4" brick masonry	.8
4" poured concrete wall	.8
4" glazed tile masonry	.12
8" concrete block	2.4

¹ From ASHRAE Handbook of Fundamentals, 1967

Table VII. Animal Heat Production

Type of heat	Animal			
	Sow & Litter ¹	Hogs ²	Poultry ³	Dairy Cattle ⁴
Sensible heat (Q_s)	320 Btu/hr cwt	293 Btu/hr cwt	31.2 Btu/hr bird	230 Btu/hr cwt
Latent heat (Q_L)	205	127	13.0	110
Total heat (Q_A)	525	420	44.2	340
1. At 60°F temperature inside building. 2. At 50°F building temperature and 150 lb animal. 3. For 5 lb bird at a building temperature of 55°F. 4. For dairy cattle in general at 50°F building temperature.				

APPROXIMATE VENTILATION RATES

Minimum (winter)

Hogs.....3 air changes per hour
 Dairy6 air changes per hour
 Poultry30 cubic feet per hour per bird

Summer

Hogs.....60 to 90 air changes per hour
 Dairy24 air changes per hour
 Poultry300 cubic feet per hour per bird